

RESEARCH ARTICLE

# Science, Uncertainty, and Values in Ecological Restoration: A Case Study in Structured Decision-Making and Adaptive Management

Lee Failing,<sup>1</sup> Robin Gregory,<sup>2,3,4</sup> and Paul Higgins<sup>5</sup>

## Abstract

This article demonstrates a structured and collaborative approach to decision-making in the context of adaptive management experiments, using a case study involving the restoration of a hydrological regime in a regulated river in western Canada. It provides a framework based on principles of decision analysis for structuring difficult multi-attribute decisions and building the trust and technical capacity needed to implement them. Participants included ecologists and fisheries biologists, government regulators, electric utility employees, and representatives of aboriginal communities. The case study demonstrates a values-based approach to implementing adaptive management that addresses some of the long-standing difficulties associated with integrating adaptive management into

restoration decisions. It highlights practical methods for incorporating participants' values concerned with learning, cultural quality, and stewardship as part of developing a decision-making and monitoring framework for restoration initiatives. It also provides an example of how to implement principles of meaningful consultation in a restoration context, with emphasis on ensuring that all voices and concerns are heard and meaningfully incorporated. Participants have adopted the framework as a model to guide future collaborative decision-making processes involving Aboriginal communities, regulatory agencies, and other parties.

**Key words:** aboriginal, adaptive, consultation, deliberation, group decisions.

## Introduction

Research and literature on restoration science provides a sound basis for efforts to restore ecological systems that have been altered by human development. Yet the fact that these systems need restoration means that there are competing demands for their services. Usually, there is also substantial uncertainty about the success of proposed restoration efforts. This means that making informed choices about whether and how to restore ecological systems will involve more than science: value-based trade-offs among multiple objectives will also be critical, as will learning about project impacts on biophysical systems and potential economic and social outcomes. Making choices will involve finding ways to work collaboratively with a diversity of people and organizations who care about both the outcome of restoration decisions and the process by which such decisions are made. Although there are frequent calls for "meaningful consultation," relatively few examples exist of what this means in a restoration context.

This article demonstrates a structured and collaborative approach to decision-making in the context of adaptive management experiments, using a case study involving the restoration of a regulated river within the traditional territory of an aboriginal community in Canada. The restoration framework, based on principles of decision analysis, helps to structure difficult multi-attribute decisions and to build the trust and technical capacity needed to implement them (Cipollini et al. 2005). We believe it provides one example of meaningful consultation in the context of restoration decisions.

This article contributes to an active debate, unfolding over the past decade, concerning the relative roles of scientific and values-based inputs in defining and implementing restoration projects (Davis & Slobodkin 2003; Winterhalder et al. 2004). The Society for Ecological Restoration International (2002), for example, provides guidance on how to plan, conduct, and evaluate restoration activities. Some of these same issues reappear in the Principles and Guidelines for Ecological Restoration developed by Parks Canada (2009), whose stated purpose is to provide "a practical framework for making consistent, credible, and informed decisions about ecological restoration." From our perspective, the key issue is not science versus values—clearly both are essential to sound restoration initiatives—but rather how science (including biological uncertainty) and values (including objectives and measures) are incorporated as part of an overall

<sup>1</sup>Compass Resource Management, Vancouver, BC Canada

<sup>2</sup>Decision Research, Eugene, OR USA

<sup>3</sup>Value Scope Research, Galiano, BC Canada

<sup>4</sup>Address correspondence to R. Gregory, email robin.gregory@ires.ubc.ca

<sup>5</sup>B.C. Hydro, Vancouver, BC Canada

decision-making framework, one that provides explicit comparisons across alternatives and that facilitates informed deliberations among the various interested parties.

We illustrate these points using a case study example of what is termed Structured Decision Making (SDM), a prescriptive approach to environmental decision-making that facilitates better choices based both on theories of rational choice and the judgmental limitations of decision-makers and stakeholders (Gregory et al. 2012). The case study site is the Bridge River, historically a large (Mean Discharge = 100 cms/y) glacially fed tributary of the Fraser River in the Coast Mountain Range in southwestern British Columbia, Canada (Hall et al. 2011). After construction of Terzaghi Dam in 1960 as part of the Bridge–Seton hydroelectric project, there were no continuous flows in the river downstream of the dam (the Lower Bridge River). Flows were restored by court order in the late 1990s in an effort to bring back some of the ecological functioning of the river below the dam. However, there was significant uncertainty about the benefits of different flow releases, especially for highly valued salmon populations (Failing et al. 2004). Historical records indicated that prior to regulation, most of the best fish habitat was upstream of the dam (now flooded by the reservoir), while the river below the dam site was fast and cold—primarily used for the passage of anadromous fish to and from spawning areas (O'Donnell 1988). This, coupled with the high economic value of the water for generating electricity, led to the acceptance that any new flow regime would be largely independent of the river's historical condition (Bradford et al. 2011). Yet there remained significant uncertainty about how flows would affect ecological (and particularly salmonid) productivity and, as a result, considerable controversy over decisions about how to restore the hydrologic regime of the river.

To address this uncertainty, the Lower Bridge River became the subject of ongoing adaptive management efforts (Holling 1978; Walters 1986; Lee 1993). Although adaptive management has become widely accepted in restoration management, there remain significant challenges in implementation. A variety of reasons have been identified (Walters and Green 1997; Gregory et al. 2006b); a central difficulty is that resource management decisions typically result in impacts on a variety of environmental, economic, social, and/or cultural or health considerations. This multi-attribute nature of effects means that choices about which management action to implement will involve difficult value trade-offs. Getting the science right is a key element in making informed restoration decisions, and good science has been the primary focus of most adaptive management initiatives. Yet whenever there are conflicting values and multiple stakeholders, good science alone does not produce decisions. There is increasing recognition that to be successful, an adaptive management process must follow a sound decision-making process and meaningfully engage other government participants and external stakeholders, including a mechanism for dealing with different stakeholder values and risk tolerances over uncertain outcomes (Gregory et al. 2012).

Adaptive Management involves exploring alternative ways to meet a range of management objectives, predicting the

outcomes of alternatives based on the current state of knowledge, implementing one or more of these alternatives, monitoring to learn about the impacts of the selected management actions, and then using the results to update knowledge and adjust management actions (Walters, 1997). On the Lower Bridge River, the focus has been learning about the effect of various downscaled seasonal flow regimes on the fish community (mainly juvenile salmonids; Bradford et al. 2011), on key indicators of aquatic and riparian response (benthic community indicators, riparian black cottonwoods; Hall et al. 2011), and on several indicators of cultural and social response (stewardship, cultural, and spiritual quality).

Four years (1996–1999) of baseline monitoring preceded the initial flow release in 2000. Prior to the release, the channel immediately below the dam was restored with a pool-riffle structure, and side channels and spawning beds were added (Decker et al. 2008). The initial release was based on an annual water budget equivalent of a mean discharge of 3 cms/y. In 2001–2003, a comprehensive water use planning process (Failing et al. 2004; Gregory et al. 2006a) resulted in a decision to implement a series of experimental flow releases, beginning with a continuation of the 3-cm/s flow; a review period of 4–6 years was established to evaluate the monitored results of each subsequent trial. In this article, we describe the decision-making framework developed for this review, drawing on principles of SDM, adaptive management, and meaningful consultation.

## Methods

### Structured Decision Making

SDM draws on the principles and tools of decision analysis, based on multi-attribute utility theory (Keeney & Raiffa 1993) and has enjoyed extensive application to ecological problems characterized by significant biological uncertainty (Walters & Green 1997). SDM approaches also emphasize the deliberative and process aspects of environmental decision-making—how decisions are made, as well as what management actions are undertaken—and thus also are based on behavioral decision research from psychology and the decision sciences (Slovic 1995; Kahneman 2011). Core elements of SDM include defining objectives and measures of performance, identifying and evaluating alternatives, and making choices based on a clear understanding of uncertainties and trade-offs (Fig. 1). SDM methods have been adapted to a variety of applied resource management problems in North America and elsewhere (Cipollini et al. 2005; Lyons et al. 2008; Gregory & Long 2009). Although some applications use quantitative multi-attribute trade-off methods to weight objectives and score alternatives, SDM more commonly focuses on good problem structuring and a deliberative approach to decision-making (Gregory et al. 2006a).

### Adaptive Management

Adaptive management has always been about linking science and management (Walters 1986), yet early representations

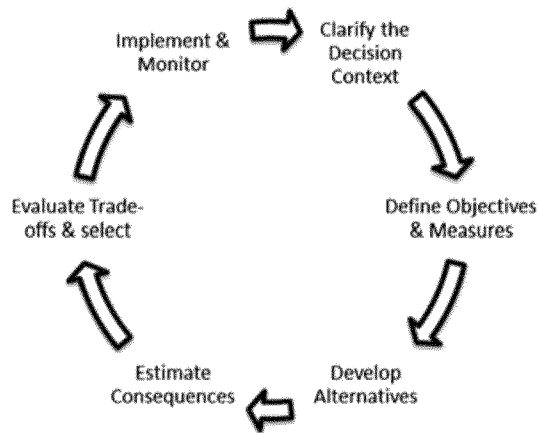


Figure 1. The structured decision-making process.

of the adaptive management cycle tended to focus on the science side of the equation (Fig. 2a). Core decision-making steps like setting objectives and defining alternatives were encompassed in the “assess the problem” step and were not well described. More recent representations (Fig. 2b), such as that provided in the US Department of the Interior’s “technical guide” to adaptive management (Williams et al. 2007), focus explicitly on core decision-making steps and processes that engage stakeholders. We note a strong similarity between the steps in Figure 2b and the SDM decision-making process used on the Lower Bridge River (Fig. 1).

### Meaningful Consultation

Defining what constitutes “meaningful consultation” and achieving it is an important goal with respect to stakeholders in general, but it has proven particularly challenging with respect to aboriginal communities. In Canada, as in much of the world, “consultation” with aboriginal people is mandated by law. As we have noted elsewhere (Gregory et al. 2008),

current approaches to these consultations tend to begin with legislative mandates, information-sharing protocols, and legal agreements designed to get parties to the table. They proceed to negotiations in which parties are presumed to know what the options are, what consequences are likely, and which alternatives are thus preferred. An essential missing element is the part in the middle, where the parties mutually develop objectives, learn about management options and their consequences, gain an understanding of uncertainty, and address difficult tradeoffs (Gregory et al. 2012). SDM helps to fill that gap.

### Experimental flows on the Lower Bridge River

Initial adaptive management efforts on the Lower Bridge River focused on two primary objectives, salmon abundance and revenues from power production. Salmon abundance served as a proxy for a variety of social and ecological values. Additional objectives related to wildlife and riparian health and to Aboriginal cultural considerations were identified through the course of deliberations and were then included to various degrees in the monitoring program.

As the first flow trial neared completion, a multi-party working group (WG) was established to review the results. Members of the WG included the provincial utility (BC Hydro), the federal regulator (Department of Fisheries and Oceans), the provincial Ministry of Environment, and the St’at’imc Nation, an Aboriginal community whose traditional territory includes the Lower Bridge River. Monitoring data and expert judgment provided high quality information about effects on the end-points, but it was evident that there were residual uncertainties (Bradford et al. 2011) and that choosing a flow regime—even for the next experimental treatment—would require making value based choices about risks and trade-offs. While the ecological benefits of wetting the previously dry channels of the upper reaches were clear, the incremental benefits of adding more water to the lower reaches were less clear (Fig. 3). The review of the results also demonstrated that additional

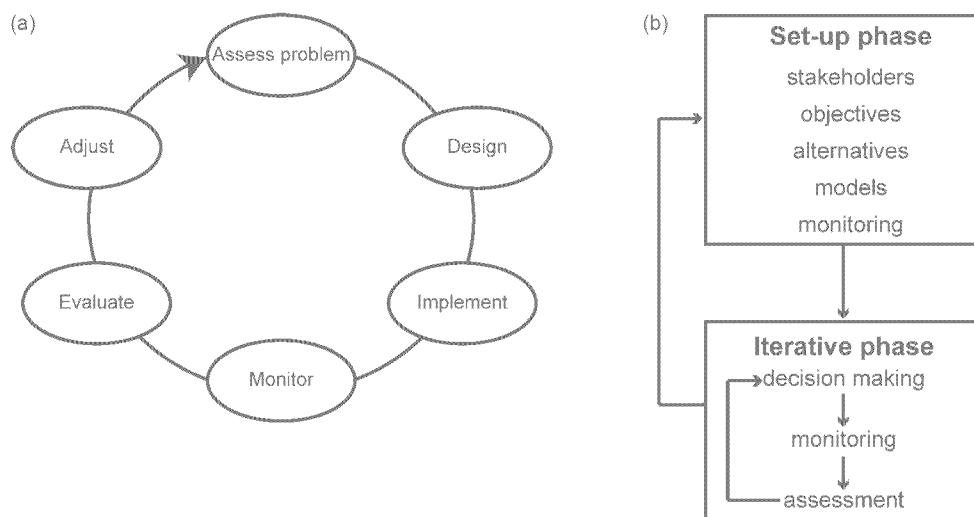


Figure 2. The Adaptive Management Cycle (adapted from Williams et al. 2007).

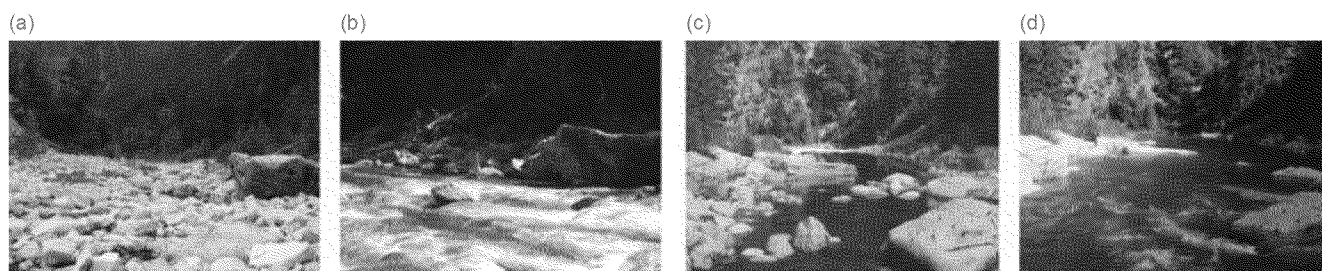


Figure 3. Photos showing Lower Bridge River reaches 4 (Previously dry) and 3 at 0 and 3 cm/s. (a) Reach 4 at 0 cm/s, (b) Reach 4 at 3 cm/s, (c) Reach 3 at 0 cm/s, and (d) Reach 3 at 3 cm/s.

social, environmental, and cultural objectives—beyond those included in the original decision context—were relevant to the evaluation of the flow alternatives, particularly for the St’at’imc. As part of a new relationship between the St’at’imc, the utility and the regulators, all parties were interested in addressing these multiple concerns with the same thoughtfulness and rigor that had produced insights from a fisheries science perspective.

These factors led to the choice of a SDM framework that would (1) provide an explicit a priori framework for decision-making on the basis of experimental results and (b) involve aboriginal participants and meaningfully incorporate their values and perspectives. By establishing the framework proactively, we sought first to ensure a clear upfront understanding among the parties on the criteria and process for making flow decisions and, second, to lay the groundwork for appropriate data to be collected over time.

## Results

### Decision Context

Over the course of the first trial, many things influencing decision-making on the Lower Bridge River changed—scientific understanding of the system, value judgments about what mattered, and political agreements that governed who needed to be involved and how. This led to a recognition that both new objectives and new alternatives should be considered and that new participants would need to be involved in new ways.

The immediate decision facing the WG was focused on the next phase of the experimental flow trials, specifically: whether to stop testing and revert to the 0-cm/s situation, stop testing and accept the 3-cm/s flow, or test the 6-cm/s (or another) flow. It was noted that future decisions could involve choices among different flow options as well as different combinations of flow options and habitat enhancement options. Thus the WG designed the decision-making framework to contain the elements necessary for evaluating a full suite of restoration alternatives.

### Objectives and Measures

The WG began by identifying the different types of concerns that might be affected by flow alternatives and, after

discussion, agreed on a common set of objectives. These became the evaluation criteria for the outcomes that would be considered when evaluating alternatives. Each objective has an accompanying performance measure, a specific metric for reporting progress toward the objective. The measures are initially predicted but, as experimental results are delivered, are then assessed in the field.

The selected performance measures are of three different types: natural, proxy, and constructed (Keeney & Gregory 2005). Natural measures directly describe the endpoint in clearly understandable units. For example, an objective to minimize revenue losses might be reported in dollars. Proxies are indirect measures of something that is hard to value directly. Constructed measures are used when no suitable natural measure exists or when the relevance of a proxy measure is tenuous. In the most common type of constructed measure, discrete levels of effect are defined that are relevant for the decision problem at hand and given both labels (low/medium/high, or ordinal ranks from say, 1–5) and narrative descriptions. The identified objectives and measures are summarized below and in Table 1.

Salmon are valued for their cultural and spiritual importance to the St’at’imc Nation, for their importance to commercial and sport fisheries, and for their contribution to broader ecosystem health.

River Health is a complex ecosystem objective; for this decision, good proxy measures are related to the abundance and diversity of the benthic community.

Riparian Health, also a complex objective, is based on the expected growth rates of black cottonwoods as a proxy measure.

Stewardship is defined as a responsibility to manage the ecological health of the Bridge River system in a way that is sustainable and takes account of future generations (Table 2). Although stewardship might have limited usefulness when comparing different flows, it was agreed that some non-flow alternatives such as habitat enhancement and monitoring activities could encourage greater participation and collaboration among management agencies and communities.

Cultural and Spiritual Quality includes the smell, sound, sight, and feel of the river. In meetings with members of the WG, St’at’imc elders spoke of the “spirit” or “voice” of the river and observed that, in moving from a water budget

**Table 1.** Objectives and measures for Lower Bridge River restoration.

<i>Objectives</i>	<i>Performance Measures</i>	<i>Type</i>
Salmon	Total salmon biomass, over species and reaches, with reference to possible losses or trade-offs	Natural scale (kg)
River Health	Abundance and diversity of benthic community (percent aquatic insects in the Ephemeroptera, Plecoptera, and Tricoptera taxa); Total abundance; Simpson's diversity index	Proxy
Riparian Health	Expected growth rate of black cottonwoods: adult growth rate, juvenile growth rate, recruitment success	Proxy
Stewardship	Ecological performance; level and quality of participation; long-term commitment to oversight, monitoring and capacity building	Ecological endpoints and constructed scale
Cultural and Spiritual Quality	Smell, sound, and movement of the river with reference to its spirit and voice, also the interaction of people and water (e.g. ability to walk in/across the river)	Constructed scale
Learning	Quality, reliability, and breadth of knowledge (both scientific and traditional)	Constructed scale
Financial Impact	Changes in the value of electricity production, also annualized implementation costs for habitat projects	Natural scale (\$)

**Table 2.** Five-point stewardship scale for Lower Bridge River restoration trials.

Poor	One or more of the key parties are not included in active participation and stewardship opportunities are limited.
Fair	All of the key parties are involved but stewardship opportunities are limited.
Good	All key parties are fully involved, and there are moderate opportunities for active stewardship by key parties and affected communities.
Very Good	All key parties are fully involved and there are significant opportunities for active and collaborative stewardship, but with limited long-term financial and institutional commitment.
Excellent	All key parties are fully involved, there are significant opportunities for active and collaborative stewardship and there is a commitment to active and on-going oversight, monitoring, and capacity-building.

of 0 cms/y to 3 cms/y, there were improvements in both the cultural quality of the river and ecological measures. Importantly, the four components of this measure only define what is most relevant for the evaluation by St'at'imc of the suite of alternative flow regimes and habitat enhancement activities under consideration for the Lower Bridge River.

Learning describes what will be learned about how the river (and associated ecological and social outcomes) responds to different management actions.

Financial Impact, measured in dollars, includes changes in the value of electricity production and implementation costs associated with habitat improvement projects.

### Alternatives and their Consequences

Three main alternatives were considered. The first alternative is the base case for this analysis and consists of a discharge of 0 cm/s from Terzaghi Dam. The second alternative is the 3 cms/y water budget that has been released from the dam for the past 6 years. The third is the proposed 6 cms/y water budget, a proposal stemming from the previously agreed-to Water Use Plan. Thus the choice facing the WG was to stop testing and revert to the 0 cm/s, stop testing and accept the 3-cm/s flow, or test the 6-cm/s flow.

Because an extensive monitoring program was in place over this period (and extending into the mid-1990s), a comprehensive data set was available for both the 0 and 3 cms/y water budget discharge regimes. Consequences for these alternatives were estimated using this dataset, although there remained significant uncertainties about the response of ecological systems (especially salmon biomass) to changes in flow (Bradford et al. 2011). On the basis of these results, the technical team also provided hypotheses about what could be expected under the proposed 6 cms/y flow regime.

Table 3 summarizes the consequences of the two completed flow trials in the first two "alternative" columns. The color coding shows performance relative to the 3 cm/s alternative: red denotes an alternative that performs worse than the 3 cm/s alternative on that performance measure, green denotes an alternative that performs better, and clear denotes no significant difference. For the 6 cm/s alternative, the colors indicate the predicted direction of change (magnitude was not predicted.) In some cases, competing hypotheses were considered: H1 denotes the dominant hypothesis about the direction of change, H2 denotes a plausible competing hypothesis (if one exists). This "consequences table" provided participants with a common base of information about the

**Table 3.** Consequence table showing performance relative to the 3 cm/s alternative.

Objective Measure <sup>a</sup>	Units	Dir	0 cm/s	3 cm/s	6 cm/s—H1	6 cm/s—H2
<b>Salmon</b>						
Biomass—Total <sup>b</sup>	kg	H	1,548	1,898		
Biomass—Reach 3 Chinook	kg	H	214	77		
Biomass—Reach 3 Rainbow	kg	H	650	450		
<b>River Health</b>						
Benthic diversity (% EPT)	%	H	32	45		
Benthic abundance	millions	H	41,321	76,384		
Benthic diversity (Simpsons index)	Index	H	0.45	0.63		
<b>Riparian Health</b>						
Cottonwood—Adult growth	mm/yr	H	4.30	4.60		
Cottonwood—Juvenile growth	mm/yr	H	1.90	3.90		
Cottonwood recruitment	Yes = 1; No = 0	H	0	1		
<b>Financial impact</b>						
Value of lost electricity generation	million \$ per year	L	\$ -	\$ 4.50		
<b>Cultural Quality<sup>c</sup></b>						
Voice of the River scale	Scale 1–5	H				
<b>Learning</b>						
Learning scale	Scale 1–5	H	1	3		
<b>Stewardship</b>						
Stewardship scale	Scale 1–5	H	1	2		

Red denotes an alternative that performs worse than 3 cm/s on that performance measure, green denotes an alternative that performs better, and clear denotes no significant difference.

<sup>a</sup>Two hypotheses are shown under the 6 cm/s alternative. H1 is the dominant hypothesis about the direction of change. H2 is a plausible competing hypothesis (if one exists). The shades show the predicted direction of change (relative to 3 cm/s) under each hypothesis. The magnitude of change was not estimated.

<sup>b</sup>Biomass Total shows differences in total salmonid biomass across all species and reaches. A detailed review by species and by reach exposed trade-offs with respect to chinook and rainbow trout in reach 3. These were considered in decision making.

<sup>c</sup>The Cultural Quality scale is under development, although direction of change from 0 to 3 cm/s is clear, and a direction of change under 6 cm/s is hypothesized.

consequences of different flow regimes on objectives and provided a basis for focused discussions about the risks and benefits of different flow regimes.

For salmon biomass, only the performance measures relevant for decisions are shown. On an aggregate basis, data show that salmon (including among others, chinook, coho, and rainbow trout) biomass had risen under the 3-cm/s flow. However, analysis by reach and species showed that biomass was down in reach 3, caused by losses in chinook and rainbow trout. These results suggest potentially important uncertainties and trade-offs at the species and reach level that formed a significant part of the deliberations, as discussed below.

#### Choosing a Preferred Alternative: Evaluating Uncertainties and Trade-offs

Choosing a preferred alternative involves consideration of trade-offs and uncertainties. Sometimes these trade-offs are across different objectives—for example, should we give up power benefits for fish benefits, or should we accept losses to chinook in order to achieve gains in overall salmonid biomass? Sometimes trade-offs are rooted in risk tolerance—for example, the range of possible chinook outcomes under one alternative is greater than the range of chinook outcomes for another. In such cases, we need to ask: how much risk are we willing to accept in order to explore the possibility of greater gains? The answer will vary across people and objectives.

To address these questions, we used a deliberative approach that began by comparing pairs of alternatives, looking for dominated alternatives (alternatives that are outperformed on all performance measures by one or more of the other

alternatives), and insensitive performance measures (measures that either do not vary or that co-vary across the full set of alternatives). This did not eliminate any alternatives in this case, but it did eliminate many salmon biomass measures (outcomes for particular species and reaches that co-varied with total biomass). Table 3 highlights the following key trade-offs and uncertainties:

- Moving from 0 to 3 cm/s has resulted in gains in overall salmon biomass, but losses to chinook and rainbow trout in reach 3. There are competing hypotheses about the causes of this outcome.
- River health, as reported by benthic abundance and diversity, has unambiguously increased under 3 cm/s. However, this is largely attributed to the rewetting of previously dry channels, and as a result the predicted incremental gains of moving to 6 cm/s (from 3 cm/s) are not significant.
- Riparian health, as reported by cottonwood recruitment and growth, has increased under 3 cm/s. Again most of this is attributable to rewetting of dry channels; an exception is the existence of a competing hypothesis for adult cottonwood growth.
- The estimated cost of the 3-cms/y flow is \$4.5 million per year; the incremental cost of 6 cm/s relative to 3 cm/s is expected to be similar.
- Cultural quality has improved under 3 cm/s, and while the cultural quality scale is still under development, the predicted direction of change under 6 cm/s is positive.
- Learning has improved under 3 cm/s. Interestingly, there are competing hypotheses about the extent of measurement

error under a 6-cm/s release, resulting in uncertainty in the benefits for learning.

- Stewardship has improved under 3 cm/s (there being more opportunities for stewardship when channels are wetted rather than dry) but is unlikely to improve further under 6 cm/s.

A key part of the learning and deliberations about selection of preferred alternatives hinged on the WG's conclusion that there could well be negative impacts on chinook as a result of the 3-cm/s test flow, the magnitude and severity of which remained uncertain, and that these impacts could be exacerbated under a 6 cm/s water budget flow regime. Identifying ways to mitigate these risks (by altering hydrograph shape, altering discharge temperatures, and enhancing monitoring) became an important focus of deliberations and a revised hydrograph shape was developed—see the Discussion section.

Given the large number of demonstrated benefits of a 3-cm/s flow release relative to 0 cm/s, no members of the WG proposed halting the flow trials and reverting to a 0-cm/s flow. However, given the modest estimates of predicted benefits across all objectives of a 6 cm/s water budget, and the concerns over potential risks to chinook, the WG considered stopping the flow trials and beginning immediate implementation of a program of habitat enhancements designed to complement a 3 cm/s water budget flow regime. This would result in immediate realization of the benefits of habitat enhancement rather than deferring those benefits for another flow test period. The choice between these alternatives depended in large part on willingness to accept varying degrees of risk. After further discussions with St'at'imc communities and a review of the information in the consequence tables, the WG recommended the 6-cm/s flow trial. While concerned about the potential for negative long-term chinook impacts, both WG members and local communities supported going forward with the 6-cm/s test in order to learn about the response of the river to different flows. Thus, the residual risks to chinook were explicitly accepted, conditional on changes to the monitoring and learning programs, and a commitment to seek means of mitigating risks to chinook.

### Implementing a Learning Program

A variety of changes to the monitoring program were developed as a result of the decision process, resulting in both a reduction and a refocusing of monitoring budgets to emphasize those elements of the adaptive management plan with the best prospects for learning. These changes included scaling back monitoring related to benthic health (not expected to be a key determinant of the final flow choice), initiating additional monitoring related to adult chinook, initiating changes to sampling methods to reduce uncertainties that hindered interpretation of the data, and initiating monitoring of the cultural/spiritual quality of the river. Other learning needs also were identified, largely in response to the discussions about how to achieve the Stewardship and Learning objectives; these include programs to improve information about the expected

performance of habitat enhancement programs and to enhance traditional ecological knowledge.

### Discussion

This article highlights several lessons for adaptive management initiatives that focus on ecological restoration and habitat enhancement. First, making broadly supported decisions in these realms requires not only sound science but also a value-based dialog about trade-offs across multiple objectives. Experimental and monitoring results alone will not produce a decision. In our experience, it's important to develop an explicit, structured framework for dealing with value-based judgments once experimental results are delivered; this is likely to change the nature of the information collected as well as the context and efficiency of the deliberations about what to do. In addition, deliberations of this type include emotional and ethical as well as cognitive or technical considerations. Research shows that in such situations, people draw on two systems of mental processing—a rational/cognitive system and a more emotional/intuitive system (Kahneman 2011). Informed choices require a deliberative environment that allows both of these systems to function.

Second, objectives for environmental management initiatives should include all the things that matter, even if they are hard to measure. In this project, for example, spiritual and cultural objectives were evaluated in detail, even though they are outside the normal bounds of “ecological restoration” analysis and even though we initially had no idea how we would measure them. At the simplest level, giving these previously invisible values a legitimate place in decisions demonstrated respect for St'at'imc values (Turner et al. 2008). By incorporating multiple sources of knowledge in a long-term monitoring program, it also helped to level the playing field between science and traditional knowledge, and, we anticipate, will build capacity and learning in both these knowledge realms over time.

Third, the project provides an example of a deliberative approach to trade-off analysis (Gregory et al. 2012). Readers may be familiar with more quantitative approaches to multi-attribute trade-off analysis (or decision analysis), involving explicit weighting of the independent objectives and subsequent scoring of alternatives. Although we think that these more quantitative methods are helpful (and even necessary) in some circumstances, we also have found that deliberative approaches—methods that focus on structuring the decision, clearly identifying key measures of performance, illuminating trade-offs and uncertainties across estimated consequences, and promoting explicit discussion of the associated value judgments and risks—are widely applicable in restoration contexts and can promote acceptance by diverse stakeholders of management decisions consistent with the methods and principles of both ecology and decision science.

Fourth, the SDM framework established a clear road map that focused on the decision-making task, despite the pressures of difficult value-based conflicts. For example, during the evaluation of the 6 cm/s alternative, participants realized that there were “alternatives” for the shape of a 6-cm/s hydrograph

(in other words, alternatives for how much of the 6-cm/s annual flow was delivered in each month). And so a new set of “alternatives” was developed, which consisted of variations on the shape of a 6-cm/s hydrograph. Because by this stage trust had been established, the WG could make use of a streamlined SDM process to examine these sub-alternatives. Four objectives and corresponding measures were defined (related to impacts on chinook, ability to learn, other fish impacts, and riparian health), and six different hydrograph shapes were developed and evaluated against the measures. One of these clearly dominated, outperforming all others on each of the four criteria.

Finally, we found that SDM facilitated the core goals of adaptive management—namely deliberate and rigorous learning (including but not limited to experimentation) to improve understanding of the consequences of environmental management alternatives, using these findings to influence the design or selection of new alternatives, and engaging multiple parties in collaborative decision-making. By using a decision-focused framework to guide both technical analyses and value-based deliberations, we believe that some of the problems often cited in linking adaptive management to effective decision-making and project implementation were avoided (Allan & Curtis 2005; Walters & Green 1997). A key lesson has been that although it is essential to have a plan to guide experimental work, it is equally essential to be prepared to modify that plan on the basis of new information about either facts or values.

One of the most compelling outcomes is that the St’at’imc Nation has adopted the SDM-based framework developed for the Lower Bridge River flow decisions as the basis for future collaborative environmental decision-making initiatives within their territory. They view it as a means to explicitly incorporate St’at’imc Traditional Knowledge and put them on a level playing field at the planning and negotiating table. The utility and regulators involved also view the framework as useful and appropriate for facilitating meaningful consultations among levels of government. What these participants found most helpful about SDM is its focus on mutual learning in support of collaborative decision-making, its ability to deal rigorously with both complex technical analysis and a diverse range of values, and its ability to accommodate high standards with respect to both science and local knowledge.

### Implications for Practice

Implications for restoration practice include

- Treat restoration problems as multi-objective decisions.
- Include all relevant objectives, even if they are hard to quantify.
- Do not expect experimental results alone to lead to clear restoration choices.
- Implement adaptive management within a structured decision-making framework that addresses value judgments and uncertainties.

- A deliberative approach to trade-offs within a well-structured decision problem is consistent with the principles of decision analysis.
- Recognize that long-term experimental programs need to be responsive to changing information, values, and political realities.

### Acknowledgments

Funding for the writing of this article was received from the U.S. National Science Foundation through Awards 0725025 and 1231231 from the Decision, Risk, and Management Science (DRMS) program to Decision Research. The authors thank the Working Group participants for insights offered over the course of the Lower Bridge River deliberations: W. Alexander, M. Bradford, A. Caverly, J. Korman, D. Levy, R. Louie, C. Perrin, and J. Snee. Responsibility for the views expressed in this article rests with the authors alone.

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